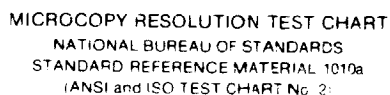
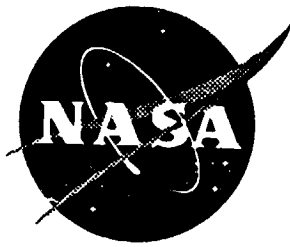


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# Integrated Helmet Mounted Display Concepts for Air Combat

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## **Abstract**

*A piloted simulation study was conducted in a dome simulator to evaluate several Helmet Mounted Display (HMD) formats developed as part of the NASA High Alpha Technology Program (HATP). The display formats conveyed energy management, spatial orientation and weapons management information. The HMD format was compared to a generic Heads Up Display (HUD) typical of current operational fighter aircraft. Pilots were tasked to spend as much time in a weapon solution as possible, to have the correct weapon selected for the envelope they were in, and to avoid the adversary's weapon envelope as much as possible. Several different displays were tested individually and simultaneously to see how separate display concepts coexisted. Objective results showed that the ability for the pilot to select the correct weapon for the envelope he was in increased by 50% in a moderate workload condition and 90% in a high workload condition with the HMD format. In the post-test comments pilots generally favored the helmet display formats over the HUD formats with a few instances where pilots preferred a simple numeric readout of the parameter. Short term exposure effects of the HMD on visual acuity were also measured and showed no adverse results.*

## **1.0 Introduction**

A piloted simulation study was conducted in a dome simulator to evaluate several Helmet Mounted Display (HMD) formats developed as part of the NASA High Alpha Technology Program (HATP). This research was conducted to address pilot vehicle interface issues that have surfaced as a result of emerging innovations in fighter aircraft design.

Advances in aerodynamics and controls have resulted in higher agility aircraft designs for air combat. For example, some new concepts (X-31) allow controlled flight up to 70 degrees angle-of-attack. With that enhanced capability comes some potential problems for the pilot. The first problem is that employing agility means reducing speed and so right away, the pilot is faced with a decision that is contrary to his training, which says *speed is life*; therefore, never sacrifice speed. The second problem is attitude awareness, since high angle-of-attack excursions can sometimes leave the pilot

disoriented. The third problem is weapons employment. Heads Up Displays (HUDs) simply cannot display the entire weapon envelope of today's sophisticated weaponry, so the pilot is forced to rely upon *rules of thumb* when making tactical weapons decisions.

HATP research was conducted to see if a Helmet Mounted Display (HMD) would help alleviate some of those problems. Hardware was chosen to exploit all available display technology. Binocular high resolution optics in the HMD made three-dimensional graphics and stereoscopic viewing possible. With those capabilities display designers had few constraints on the format of the display concepts. It was sought to have a balanced mix of graphical and digital formats to develop intuitive display concepts that meld several pieces of information. This approach potentially allows the presentation of more data in a manner that is easier for the pilot to process and comprehend. The head slaved capability of the HMD also allowed display designers to put various types of information

into different reference frames. For example, information relating to the physical world, such as attitude and heading, was placed in a world reference frame. Information relating to the target generally stayed with the target. Sorting displays into reference frames was explored as a method of providing additional information, while simultaneously reducing clutter. Except for key energy and targeting information, the pilot received information from a particular source only when he cared to look in the direction of that source. That is exactly how pilots receive information without displays, except that they have to infer exact data (target speed, heading, altitude, etc.) from visual cues.

## **2.0 Hypothesis and Experiment Goals**

The hypothesis used for this experiment was that the display concepts would not necessarily improve a pilot's natural flying abilities, but would rather improve overall tactical situation awareness and the ability to make timely decisions in that regard. Tactical situation awareness is meant to include information a fighter pilot requires during the course of an air combat engagement. Specifically, it would include energy, spatial, and weapons awareness. This hypothesis was based on experience from previous experiments and in-house research (References 1 and 2). A design goal was to eliminate some undesirable habits pilots were picking up in the previous experiment conducted with the HMD (Reference 3). One of these was that pilots were spending an inordinate amount of time at high alpha which is an inherently vulnerable energy state. Also, nearly every pilot hit the ground at least once. Another goal of the overall display design process was to ensure that a display should be usable from takeoff through mission completion to landing. For example, the display to depict angle of attack

(alpha) for air combat would ideally be just as usable for a precision landing.

The other concern in addition to the display concepts themselves was the hardware presenting those concepts. An issue raised when using artificially generated stereoscopic imagery is the short term exposure effects on depth perception. Particular care must be taken to ensure that there is no adverse effect on real-world visual perception. In a tactical environment there are many situations that rely heavily on accurate depth judgment, such as formation flying and landing. It was desired to obtain preliminary short term exposure data to determine effects on visual acuity.

## **3.0 Support Hardware and Software**

### **3.1 Simulation Facility**

This study was conducted in the Langley Differential Maneuvering Simulator (DMS) (References 4 and 5). The DMS is a visual flight simulator housed in a 40-foot diameter projection sphere with a dynamic earth-sky scene and target aircraft image. The cockpit of the DMS is a generic fighter with three heads down Cathode Ray Tube (CRT) displays and a 20x30 degree Heads Up Display (HUD). The controls were programmed for an F-18 aircraft with thrust-vectoring capability and hosted on a mainframe computer. The target image was driven by the Langley Paladin model (References 6-8). Paladin is a set of software routines which control an aircraft model (F-18 in this case) that provides a maneuvering adversary for air combat engagements.

### **3.2 Helmet Mounted Display**

The test display device for the experiment was the Langley-developed HMD shown in

Figure 1. Two one-inch monochrome Cathode Ray Tubes (CRTs) provided the image source. Each CRT was independently driven by a graphics workstation at 1280 picture elements horizontally by 1024 picture elements vertically. The images were collimated through an optical train and projected on two 50 degrees holographic optical elements. The rectangular

(Reference 9) was used to drive the display concepts and to interface the mainframe host computers with the graphics workstations. That package allowed the researcher to view the overall air combat engagement and simultaneously monitor performance measures and aircraft state parameters on a third graphics workstation in real-time (Figure 2). VISION provided a seamless

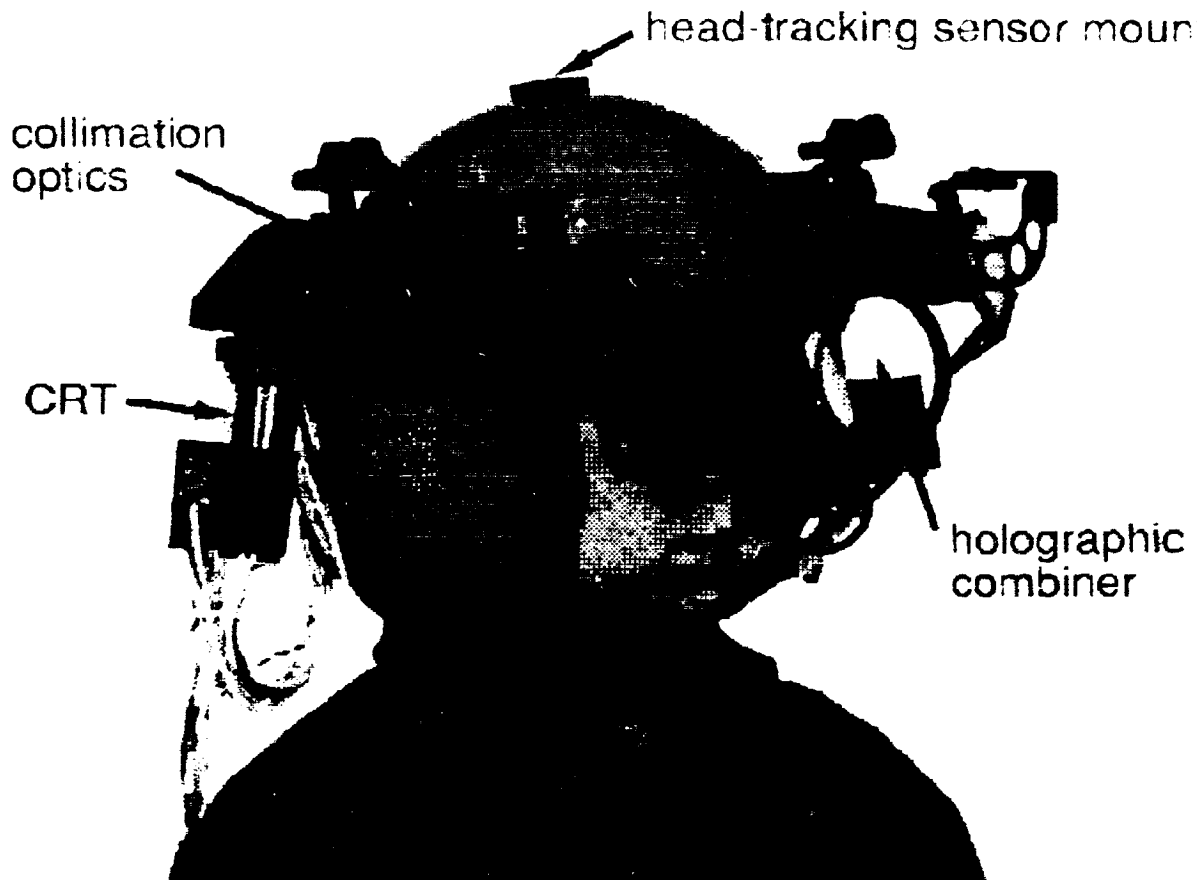


Figure 1. Langley Helmet Mounted Display

instantaneous field of view was 32 degrees vertical by 40 degrees horizontal with a 30 degrees stereo overlap region. A magnetic headtracker provided line of sight information to the graphics workstation.

### 3.3 Supporting Software

The Langley Visual Interface for Simulation and Monitoring (VISION) software package

software transition from the display development portion of the project through final testing and data collection.

## 4.0 Display Description

### 4.1 HUD

The HUD format was based on the F-18 HUD, which is representative of what is

available in a modern fighter. The HUD format is shown in Figure 3. The only FA-18 non-standard display element is the alpha tape on the right side, which is merely a fixed scale with a moving pointer.

The gun aiming display (pipper) is shown in Figure 4. The inner arc is a range to target indication with one full circle being two nautical miles (nm). The pipper was fixed to the center of the HUD field of view. The

missile Launch Acceptability Region (LAR) is shown in Figure 5. Like the pipper, the inner arc represents range to target, however, one full circle is equal to 4 nm. Two triangles move along the circumference of the outer circle and represent maximum and minimum range for the selected missile. The solid line indicates optimum range, which had no meaning for the missile model chosen for this experiment (see Section 5.6).

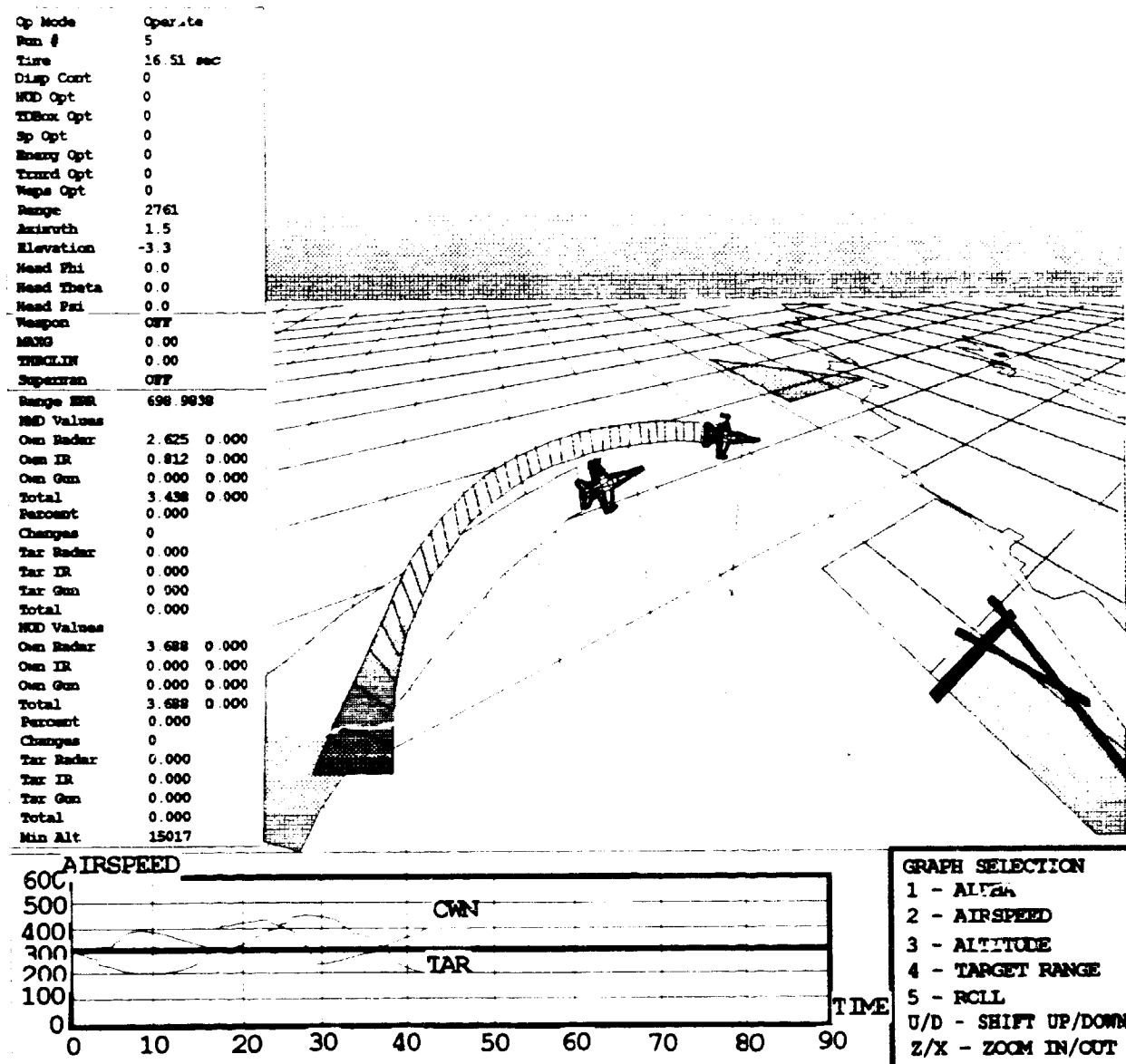


Figure 2. VISION Bird's Eye View Monitoring Software

## 4.2 Display Concepts

The integrated helmet display concepts were broken down individually to facilitate training. Formal testing was completed on the integrated design. All the displays were programmed in three-dimensional coordinates by using the IRIX GL library. A 3D rotatable font set was created by using line segments and was based on the F-16 font set, but 150 percent larger. Each of the concepts are described below.

### 4.2.1 Energy Management

The energy management display was essentially identical to the HUD displays, with the addition

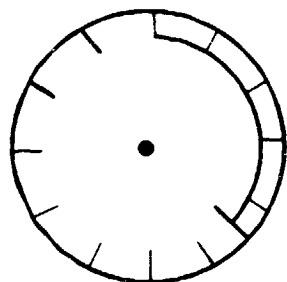
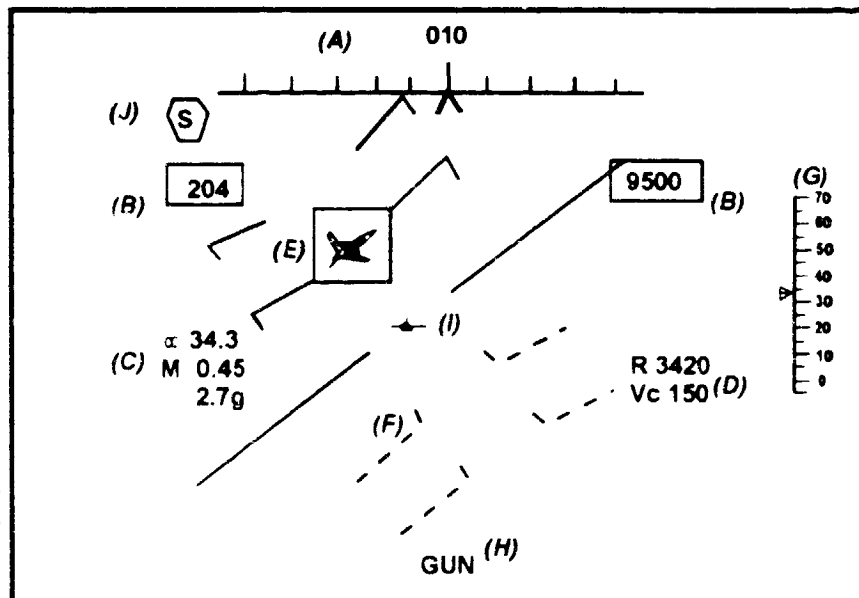


Figure 4. Gun Pipper

of a fixed scale moving pointer alpha display (Figure 6). The body of the display consisted of a fixed tape with 10 degree increments and a moving pointer with a digital alpha readout. The relative energy arrow on the left side of the fixed scale compared own airspeed to target airspeed. It commanded the pilot what to do with his alpha to match the target's airspeed. If the arrow was pointing down it was telling the pilot to release alpha, that is, the target was faster. An arrow pointing up told the pilot to pull harder, the target was slower than he was. The load



- |                                 |  |
|---------------------------------|--|
| (A) Magnetic Heading Scale      | (F) Pitch Ladder                       |
| (B) Airspeed and Altitude       | (G) Alpha Tape                         |
| (C) Alpha, Mach and Load Factor | (H) Weapons Selected                   |
| (D) Range and Closure           | (I) Flight Path Marker                 |
| (E) Target Designator (TD) Box  | (J) Superman (thrust-vectoring) Symbol |

Figure 3 DMS HUD

limit bar appeared anytime the aircraft was structurally limited from entering the high alpha region. The upper portion of the alpha tape, from 37-70 degrees, only appeared when thrust-vectoring was engaged. This feature was designed in response to the problem noted in Reference 3, where pilots were essentially unaware they had maximized their alpha capability. The appearance of the

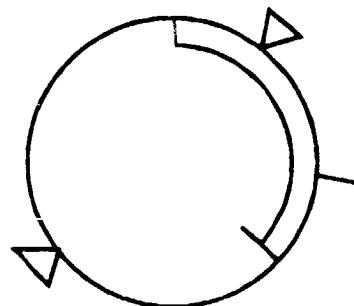


Figure 5 Missile LAR

upper portion of the tape gave the pilots a peripheral cue that high alpha mode was engaged.

There were two high drag indicators with



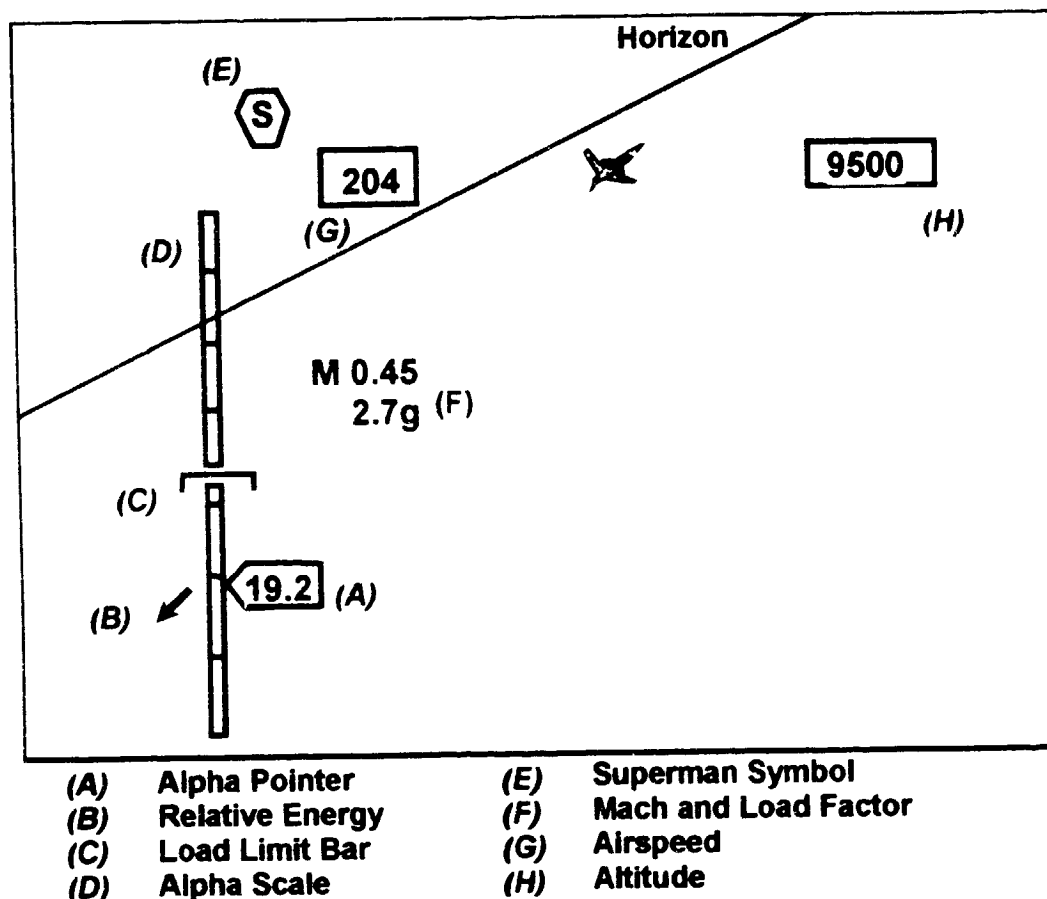


Figure 5. HMD Energy Management Displays

the energy display, which are shown in Figure 7. Basically, reverse video informed the pilot that he was in a high drag configuration.

**4.2.2 Spatial Orientation.** Two spatial orientation displays were tested in the HMD (Figure 8). The umbrella was derived from a concept developed at Wright-Patterson Air Force Base. The umbrella consisted of curved vertical lines that emanated from an apex and stretched to the horizon. Each vertical line was 45 degrees apart and represented a cardinal heading. Horizontal lines were drawn 15 degrees apart, parallel to the horizon. The umbrella was centered over the pilot's head with a radius of 500,000 feet. There was no horizon line drawn as it was assumed the horizon in the DMS would

be adequate.

The terrain warning display consisted of a horizon pointer and a steady TERRAIN warning cue twice the size of the other fonts. The cue appeared anytime the own ship was within wings level 6g's of impacting the ground. For example, in earlier testing (Reference 3) pilots tended to get in extremely nose low spirals, while fighting the adversary, and loose track of their altitude awareness. The warning cue was to avert the pilot from the intensity of the fight and to focus his efforts on the more pressing issue of terrain avoidance. The arrow was 100 milliradians (mils) wide and 200 mils high.

**4.2.3 Target Location and Weapons Management.** Refer to Figure 9 for a

<u>Airspeed</u>	<u>Alpha</u>
<div>204</div>	<div>19.2</div>
speed brakes in	< 35° alpha
<div>204</div>	<div>36.4</div>
speed brakes partially out	35° - 37° alpha
<div>204</div>	<div>43.1</div>
speed brakes out	> 37° alpha

Figure 7 High Drag Indications

diagram of the HMD weapon display. The missile icons were 3D images of an AIM-9 and AIM-120 missile, with the longitudinal axis of the missile extending into the screen. Each missile was to represent an actual missile on the aircraft so that pilots not only know the number and type of weapons remaining but, also, the physical distribution of those weapons. This knowledge can be

extremely important for weight distribution and handling characteristic, especially in a landing configuration. As missiles were shot the icons disappeared. The missile icon was wireframe until it was selected. Upon selection the missile icon turned into a solid model, and a triangle appeared to emphasize the selection of that weapon station. A digital readout showed the type of weapon

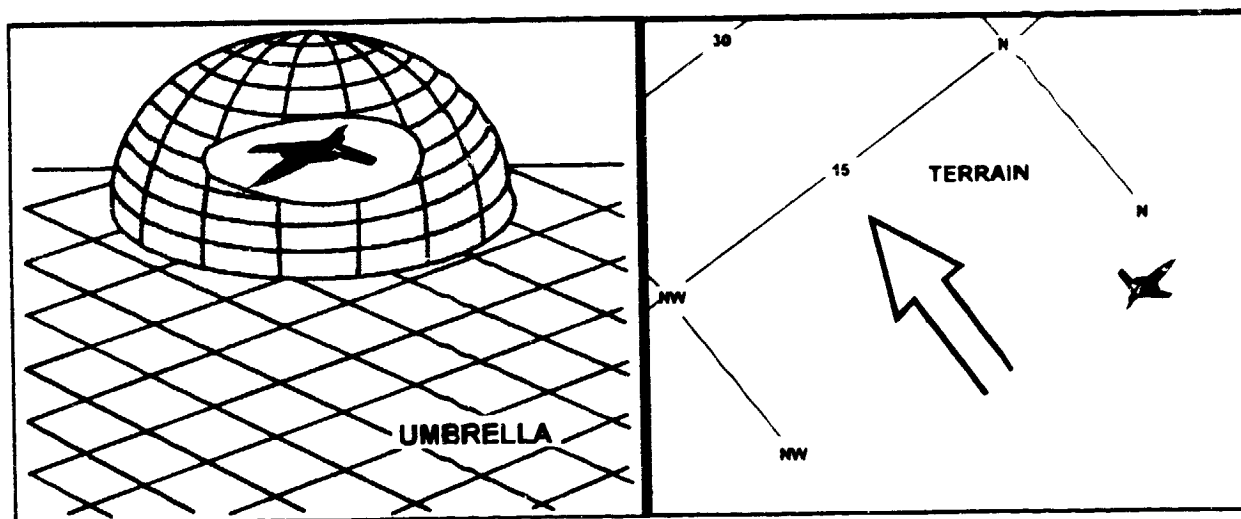
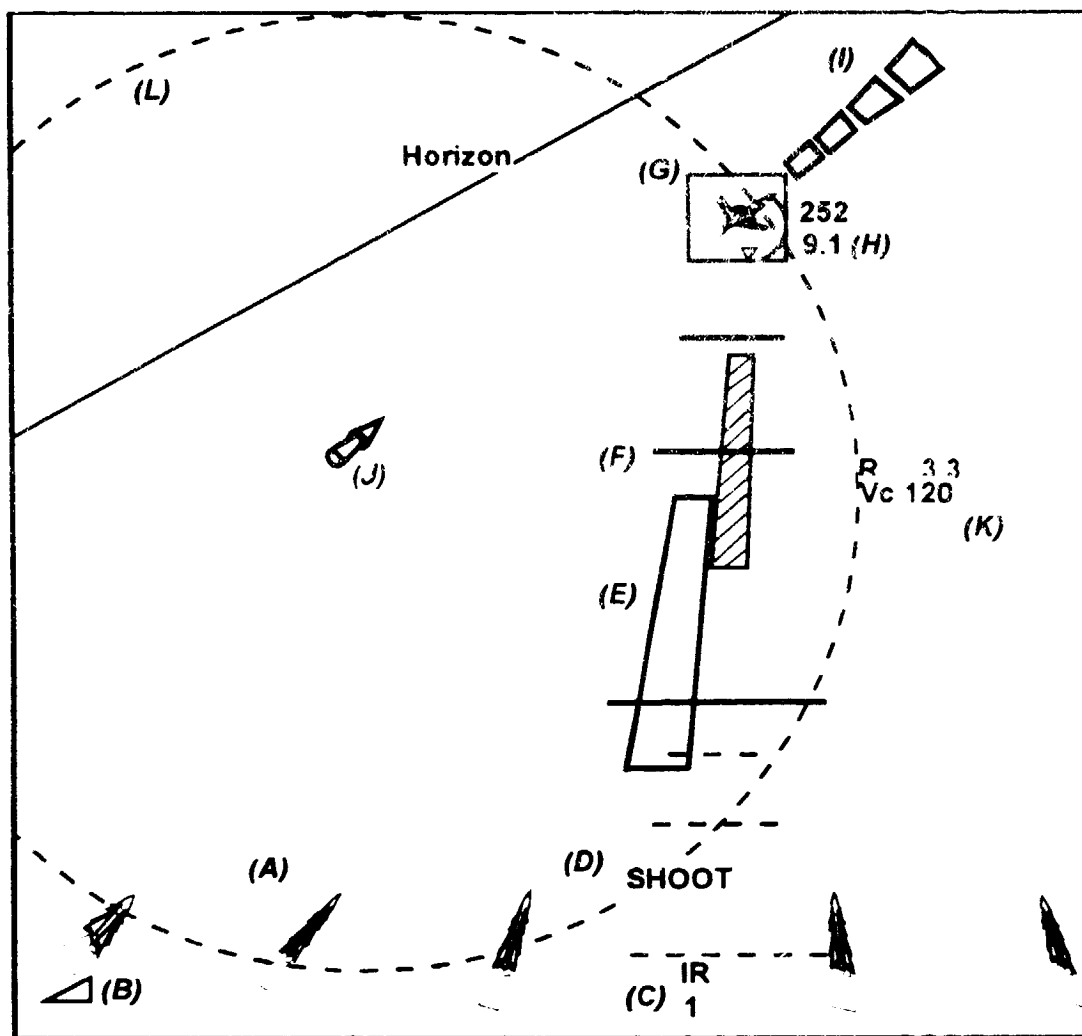


Figure 8. HMD Umbrella and Terrain Warning



- |                                   |                                     |
|-----------------------------------|-------------------------------------|
| (A) Missile Icons                 | (G) Target, Designator Box          |
| (B) Missile Selected Marker       | (H) Target Airspeed & Altitude      |
| (C) Weapons Selected Text Display | (I) Target Flight Path              |
| (D) Shoot Cue                     | (J) Target Locator                  |
| (E) Missile Range Bars            | (K) Target Range and Closure        |
| (F) Range Lines                   | (L) Allowable steering Error Circle |













Figure 9 HMD Weapon Display

selected and the number of rounds remaining. A flashing shoot cue would appear anytime all the parameters for a missile shot were met.

A visual range and closure cue consisted of a series of range lines emanating from the target. The lines were perpendicular to the

view angle, and the spacing between the lines was a function of target range. Outside of one nm the lines were one nm apart and solid. Inside of one nm the lines were 1000 feet apart and dashed. To give slightly better range resolution outside of one nm, the closest set of range lines were broken down into the dashed thousand foot increments.

Working in relation to the range lines were the missile range bars. Those bars consisted of two rectangles representing the long range radar missile and the short range IR missile. The bars were not labeled, however, the vast difference in the minimum and maximum range of those missiles leaves little doubt as to their identification. The

				
Plan View				 
Target Aspect Arc				

30

Head-line of sight

282° 9.1 9500

204

Aircraft HUD

NNE

M 0.45  
2.7g

19.2

R 3420  
Vc150

SHOOT

IR

30

N

Terrain warning not shown  
Reverse video on a/s, alpha  
to indicate high drag  
\*Disappears when declutter selected

9

achieved when the pilot flew over the top of the range bar. A valid shot required that the target also be within the steering limits for the selected missile. The allowable steering error was indicated by a dashed circle fixed to the own aircraft nose. Once the target flew in the circle the steering limitations were met.

A target designator box was used to highlight the target whenever it was within the helmet's field of view. If the target was out of the pilot's field of view, a 3D locator arrow appeared in the center of the display, which always pointed to the target. A 360 degrees radar/data-link model provided continuous data on the target. Next to the designator box was the target's airspeed and altitude, in the same units as the own ship's.

Inside the designator box was the target aspect arc (Figure 10). Target aspect is the angle that the target sees the own aircraft off of its nose. The arc was designed to accentuate that angle in conditions where the target nose position is not clearly visible. The straight solid line indicates target heading, and the triangle indicates relative own aircraft position. The display collapses to an arrow when the target is headed directly at the own aircraft. The triangle is normally hollow. When the target has a weapon solution on the own aircraft, the triangle turns solid.

The target flight path display was a series of tiles projected out of the aircraft's center of gravity. The flight path always stayed oriented with the target and projected 1000 feet in front of the target. The radius of curvature of the flight path was equal to its radius of turn.

4.2.4 Integrated Displays and Declutter Techniques. The sum of all those displays is

presented in Figure 11. Although the display may appear somewhat cluttered, that problem is reduced due to several reasons. First, not all display elements are in the same reference frame, therefore, it is unusual to see all the displays at the same time. Second, it has been demonstrated that stereoscopic displays have the potential to reduce clutter (Reference 10). Further, the display concepts were sorted for different depths.

Four reference frames were available to choose to place display elements in. They were the eye, aircraft, world, and target. Within each of those reference frames, some display elements were continuously visible, and others appeared only when the program algorithms dictated.

Careful consideration was given to what displays should always be in the pilot's eye reference frame, that is, those display elements that were always in the pilot's field-of-view no matter where he looked. The eye reference frame displayed elements that were considered crucial information, which were always visible within the energy management display (Figure 6) and the missile icons portion of the weapon display (Figure 9). Those display elements were unobtrusive and kept out of the center of the field-of-view to avoid blocking cues from the outside environment. The terrain warning display was also in the eye reference frame, appearing only when necessary as previously described, and placed in the center of the field-of-view with the premise that no other information could be more important. The target locator arrow (Figure 9) appeared just above the center of the field-of-view and was visible only when the target was not. All display elements in the eye reference frame were placed at the closest stereoscopic depth of 1000 feet from the own ship to convey to the pilot that information at this depth

pertained to his aircraft. One thousand feet was chosen as the closest distance that a real world object could be expected to be.

Only one display was fixed to the target reference frame, which was the Allowable Steering Error (ASE) Circle. The circle was large enough to only be partially visible at any head position. The remainder of the weapon display (Figure 9) was in the target reference system. Wherever the target went, those display elements followed. The stereoscopic depth of these elements was dynamic and the same as the range to the target. The exception was that the range lines and missile range bars (Figure 9) were placed at the distance they were intending to convey. For example, the range bar, which portrayed 1000 feet from the target, was stereoscopically placed 1000 feet from the target.

The umbrella (Figure 8) was in the world reference frame and was essentially placed at stereoscopic infinity. This display encompassed 360 degrees but was only placed above the horizon. Further discussion of the umbrella design is in Section 7.

## 5.0 Experiment Description

### 5.1 Procedures

The conduct of the experiment was divided into a morning and afternoon session. The morning session was a familiarization and training period, and the afternoon session

was for data collection and debriefing. Stereo measurements were taken as soon as the testing pilot arrived for a baseline measure and, again, after each session with the HMD.

#### Morning

- 1) Brief, including display familiarization in Display Lab Simulator (DLS)
- 2) Stereo acuity screening, depth perception measurements and HMD fitting
- 3) Training
  - DMS familiarization
  - HUD training
  - HMD training
- 4) Depth perception measurement

#### Break/Lunch

#### Afternoon

- 5) Warm up, one versus one training
- 6) Counterbalanced HUD/HMD one versus one engagements
- 7) Depth perception measurement
- 8) Debrief and questionnaire
- 9) Depth perception measurement

### 5.2 Subjects

Eight pilots participated in the test. The project engineer was also a former Navy pilot who had over 1000 hours of F-14 flight time, plus hundreds of hours of DMS/HMD time. His results were used in the analysis as a reference measurement, since he was considered to be a well-trained HMD pilot. His performance measures were taken and used to determine how well the test pilots acclimated to the tasks. All pilots had at least 1000 hours experience in their type aircraft. The pilot base had experience in nearly

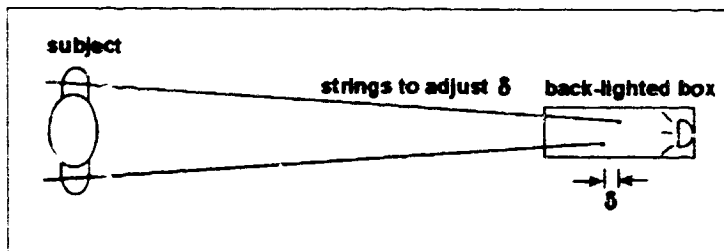


Figure 12. Howard-Dolman Apparatus

Table 1. Training Task Descriptions

Task	Display
Maintain 3000 ft. escort behind a 3g limited maneuvering target	Range, Closure, Range Lines, Pipper
Maintain $C_L$ max (36 degrees alpha) Perform high alpha maneuver	Alpha, Alpha Tape, Alpha Display
Perform loop, split S, vertical attack, bugout maneuver	Pitch Ladder, Roll Scale, Umbrell, Heading Scale

every Western fighter with the Navy, Air Force, and NASA represented

### 5.3 Visual Acuity Testing

Pilots were screened for stereo acuity with the Polaroid™ 3-D Vectograph from Stereo Optical Co., Inc. Quantitative measures were taken with the Howard-Dolman test apparatus (Figure 12), which was placed in the DMS so that a light free environment could be obtained. Reference 11 details the geometry for the Howard-Dolman apparatus. Stereoacuity was measured before any testing was begun, after each session with the HMD, and 30 minutes after the test was over. Pilots were measured immediately after climbing out of the cockpit so that their vision would not be corrupted severely from real world cues.

### 5.4 Training

Training was a very critical issue and with the HMD posed a dilemma. The HMD was uncomfortable, forcing the researcher to limit the exposure time to 45 minutes, with 30 minute breaks in between sessions. There were more than a dozen new displays, the binocular stereoscopic aspect of the helmet, and the novelty of a thrust-vectorred airplane to train to. Realistically, adequate training time would be in the tens, if not hundreds, of

hours, which was not possible given the timeline for the experiment and availability of pilots. Every attempt was made to use seasoned pilots (with more than 1000 hours and experience in more than one type of fighter) who would hopefully adapt

to the new environment, quickly.

The training syllabus was very focused with simple tasks so that there would be little to no task training time. Each task required the pilot to use one of the new HMD displays or display groups to accomplish the task. The training tasks were first run with the HUD to familiarize the pilots with both the task and the thrust-vectorred model. After those runs the pilot donned the helmet and completed the exact same sequence with the HMD. Pilots were talked through techniques to optimize the use of the displays and were instructed to ask for additional runs at any time they felt they needed additional training. The training tasks are summarized in Table 1.

### 5.5 Experiment Task

The primary source of quantitative data for the analysis was a one-versus-one (1v1) air combat task. The own aircraft was pitted against the Langley Paladin model (References 4-6). All runs started at 1,000, 5,000, or 10,000 feet with five nm separation between the own and the target aircraft. Both airplanes started co-altitude at 450 knots calibrated airspeed (kcas). Pilots were told to spend as much time in a weapon envelope as possible, while also keeping out of the target's weapon envelope. That task emulates what a typical mission may be in

peace time for a fighter, therefore, very little training was required for the task itself. Pilots were also told to have the correct weapon selected for the envelope they were in and to keep from hitting the ground. Neither aircraft's weapons were lethal, but shots could be fired at any time. The target model was identical to the own aircraft without thrust vectoring.

The first three 1v1 runs were familiarization runs to learn some of the capabilities of the models and simulator. After these runs twelve counterbalanced runs were flown for data collection purposes, six with the HUD only and six with the HMD. The HUD and all other heads down displays were shut off when the HMD was worn.

### **5.6 Weapons Models**

The weapons model for the HMD was generated on the graphics workstation and consisted of a generic radar missile, generic IR missile, and gun piper. The piper was dynamic and displayed at bullet location at the target range. The radar missile had a fixed 30 degree steering limit, and the IR missile had a fixed 15 degree steering limit. Missile range was dynamic and a function of closing speed and the angle off nose.

The HUD weapons model was generated on the main frame computer and had two missiles with simplified envelopes. Both HUD missiles had a fixed range of from 2,000 feet to 20,000 feet with the radar missile steering limits of 30 degrees and the IR missile steering limits of 15 degrees. The HUD gunsight was fixed to the center of the field of view. Pilots were considered to be in a gun envelope if they were inside minimum range for the IR missile and within one degree of the target azimuth and elevation.

### **5.7 Questionnaire**

To get an absolute as well as relative ranking of the pilot's opinion of the display concepts, a 10 point scale was used. A rank of 0 meant the display either conveyed useless information or was too hard to get information from. A rank of 10 meant that the display conveyed absolutely essential information and that it was in the perfect format. For optimum recall, pilots were asked to rank the HUD and HMD displays after performing each task.

## **6.0 Objective Results**

### **6.1 Visual Acuity**

The average differential measurement (d) on the Howard-Dolman apparatus was 1.275 cm before testing, 1.01 cm after wearing the HMD and 1.175 cm after the debrief. These numbers were not statistically significant. The worst of these equates to a visual angle of .005 degrees (.075 milliradians), which is excellent. The conclusion was that short term exposure to the HMD had no effect on lateral disparity cues. This result reinforces the findings of Reference 11 and relaxed fears of noticeable visual problems from short term exposure due to binocular stereoscopic displays.

### **6.2 Training**

Data was collected and reviewed on the training runs for learning curve differences between the two display types. There were no statistical effects to report nor were any expected. Pilots generally picked up very quickly on what was required of them and reached an acceptable level of proficiency, comparable to the project pilot.

### **6.3 1v1 Task**



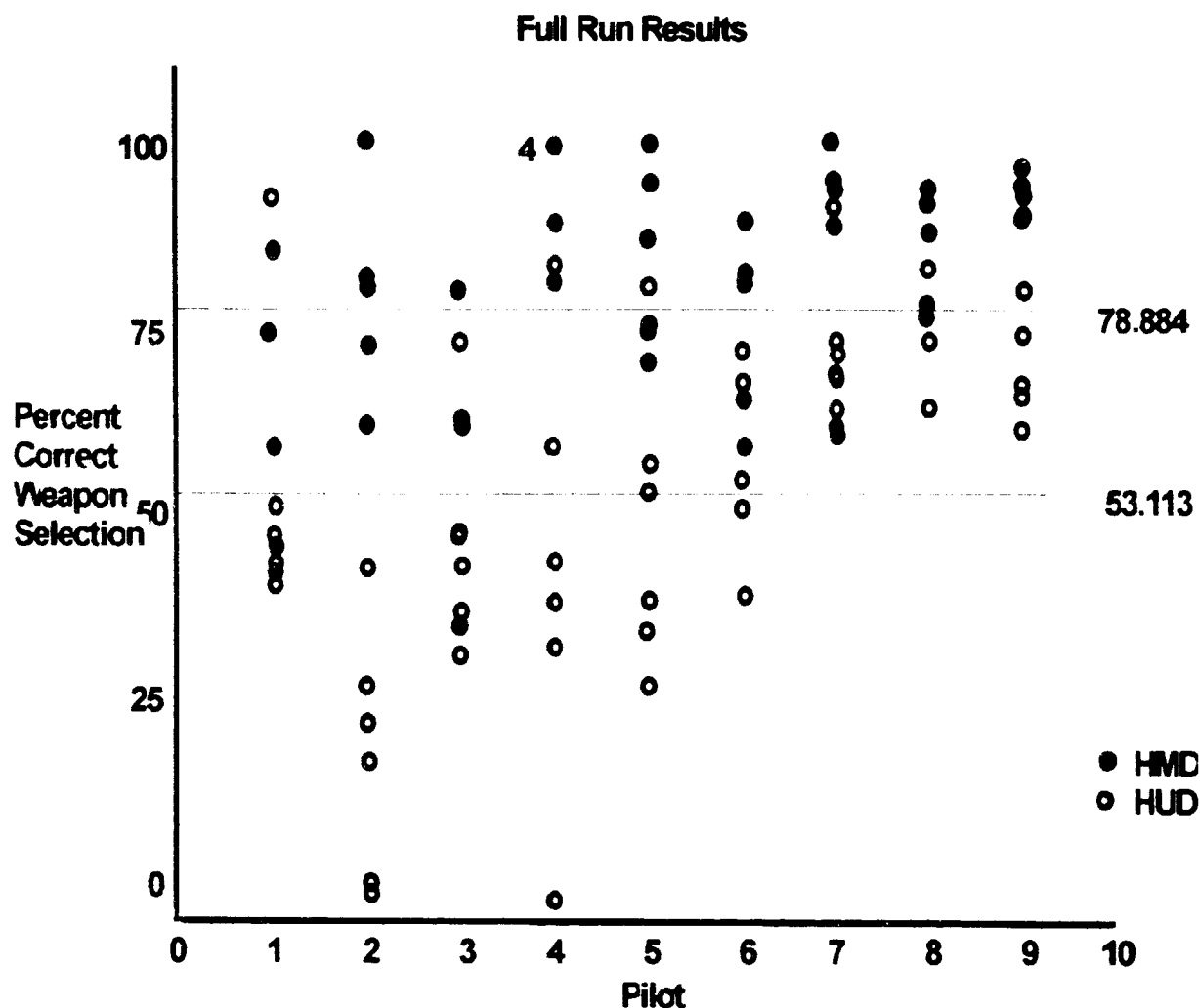


Figure 13 Objective Data For The Full Run

The performance measures analyzed in the 1v1 task included

- Difference between the time the own aircraft could shoot the target and the time the target could shoot the own aircraft.
- Percent of total time that the own aircraft pilot had the correct weapon selected for the envelope he was in
- Number of weapon changes

The first performance measure above showed no statistical difference between the HUD runs and the HMD runs. This measure

was mostly of pilot ability, and it was expected that the display format would have no effect.

The second performance measure was a good indication of pilot situation awareness, and the results obtained were significant at the .01 percent level. Results are graphed in Figures 13 and 14. If the entire run length is examined, the HMD value was 49 percent greater than the HUD value. The five mile intercept portion at the beginning of each run was excluded to examine performance just during the high workload segment. In this case the HUD performance dropped another

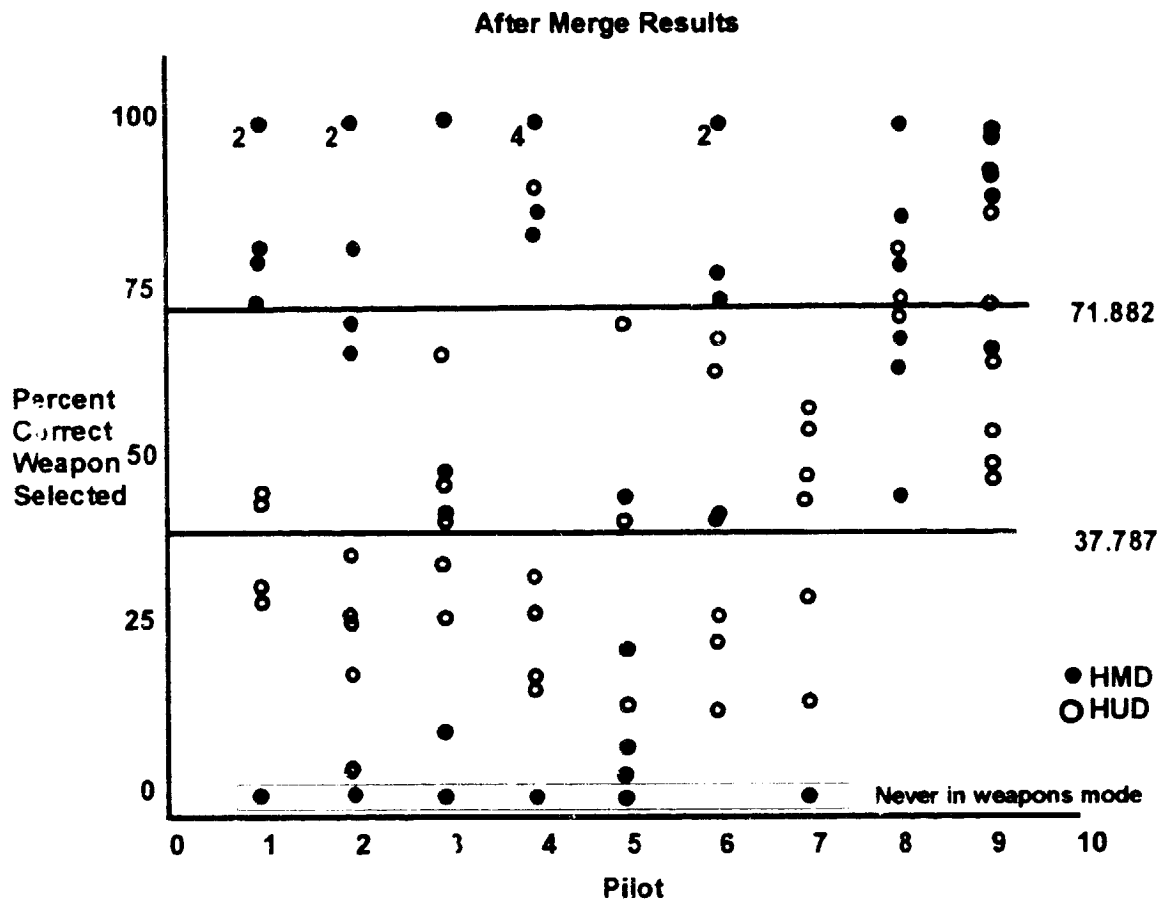


Figure 14. Objective Data After The First Merge

40 percent, whereas the HMD dropped less than 10 percent. There were also seven instances with the HMD where the pilot had the correct weapon selected 100 percent of the time, whereas no pilot had the correct weapon always selected with the HUD format. The pilot who liked the HMD weapon display the most, who was also the one who picked up on the concept the quickest, had two-thirds of his runs with the proper weapon always selected. This indicates that with adequate training the missed shot percentage will drop to nearly zero with the HMD display. These results lean more towards favoring the HMD concept when the high workload portion of the engagement is examined. For a full one-

third of all the runs, the pilots had the correct weapon always selected.

The third performance measure, the number of weapons changes between HUD and HMD, was statistically insignificant. Pilots were switching weapons equally with the two displays.

These results highlight a staggering inadequacy of conventional HUD display design. Currently, for nearly half the time a fighter pilot can shoot his adversary, he is unaware of it. The reasons for this seem to be that with the standard HUD design the weapon envelope is unknown until that weapon is selected, and the display format is

not quickly interpreted under high work load conditions. In other words, with the HUD they selected a weapon to take a guess, whereas with the HMD they selected a weapon to take a shot. In this study pilots generally missed transient missile shot opportunities with the HUD display and tended to keep guns selected more often than they should. This tendency places a severe

handicap on the fighter pilot since missiles have a greater chance of hitting the target than bullets do and are much more lethal. Additionally, gun tracking almost always requires massive energy losses making the pilot more vulnerable to unseen adversaries

## 7.0 Subjective Results

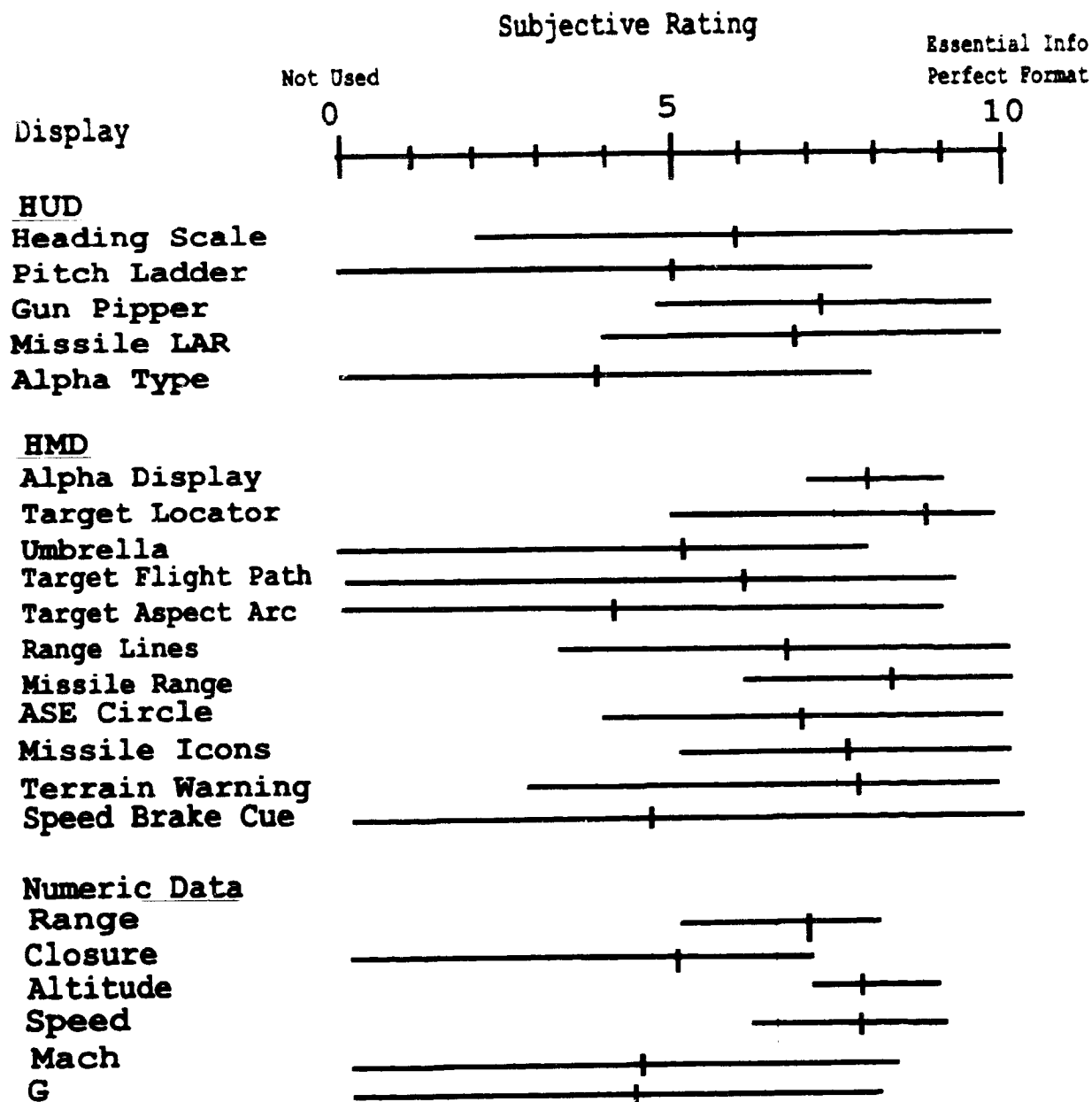


Figure 14. Overall Questionnaire Results

Displays were subjectively evaluated with the questionnaire both for specific tasks and for overall usage during air combat. It became readily apparent that the usefulness of the displays depended on the task being performed. A display may be relied on heavily in some situation but regarded as clutter in others. Nearly every pilot commented that a programmable Hands On Throttle and Stick (HOTAS) de-clutter capability would be essential with the HMD format. That would allow the pilot to choose from a library of display concepts he preferred and, then, to have the option of calling up those displays when the situation demanded their information. Perhaps better than HOTAS would be a voice activated system where the pilot would say the name of the display to toggle the information on or off.

A major factor in whether the pilot accepted the display or not was whether he had learned how to use it properly. A wide range of ranking on a display concept may be an indication that the pilots who ranked it high had received adequate training while the pilots who ranked it low did not. Overall questionnaire results are shown in Figure 14.

### **7.1 Energy Management.**

In air combat a large portion of energy management is alpha management. This is especially true for thrust-vectoring aircraft. The most challenging alpha management task required the pilot to maintain CL max (maximum Coefficient of Lift - 36 degrees) while monitoring the target position. This task is typical of a real-world air combat engagement. The HMD alpha display was the clear favorite here. Many pilots commented that they liked the appearance of the extra bar upon the engagement of thrust-vectoring. The reverse video in the airspeed

and alpha, which indicates high drag, received a few very high ranks from the pilots who picked up immediately on its utility. The reverse video falls into the category of displays that have a lot of potential once adequate training is received. The alpha tape in the HUD was preferred by one of the NASA pilots, who was very familiar to it, but the majority of the other pilots commented that they had difficulty incorporating it in their scan.

Simple digital readouts were given high ratings for both airspeed and altitude. This is understandable in that most fighter pilots tend to get their airspeed and altitude cues predominately from their environment. For example, aircraft feel and control response is a fairly good indication of both altitude and airspeed. It seems that, in air combat at least, airspeed and altitude displays give a specific value to a parameter that the pilot already has a general idea of, which is why merely a digital readout will suffice.

### **7.2 Spatial Orientation.**

Overall the umbrella ranked a 5.2 with widespread opinion of its usefulness. On a per task basis, the real utility of the umbrella was readily discernible. According to pilot ranking, no single display was capable of providing all the spatial information a fighter pilot requires. While the umbrella ranked very favorably for providing nose high attitude information, its utility for terrain avoidance is negligible. Some pilots requested a lower half to the umbrella, which may have aided in this regard. Clearly visual cues alone will not suffice for spatial orientation. While the ranking is based on the dim horizon cues in the DMS, these cues are about average visibility for the real world.

The heading scale was the preferred favorite

for the bugout maneuver. That maneuver required an immediate attention switch from attacking a target to finding which direction was west (270 degrees). Pilots felt that a finer gradient on the umbrella's horizon would have helped, and most preferred a numeric value of heading instead of the acronyms for cardinal headings (N, SW, etc.)

The terrain warning display ranked fairly high, but the 6.4 grade indicates there is room for improvement. It seems to be adequate for the time being, however, since unlike the previous experiment conducted in Reference 3, none of the pilots hit the ground during the 1v1 portion of the testing. In this previous experiment, which had a similar 1v1 task, every pilot hit the ground at least once.

### **7.3 Target Location and Weapons Management.**

The range lines were essentially on a par with the digital range readout. That is most likely due to the training task being very benign and to the difficulty in counting individual range lines. Just visual cues alone (target size, aspect, etc.) scored equally as well as the two displays for determining range to target.

The most favored display in this test, as well as the previous test (Reference 3), was the target locator arrow, ranking an overall score of 8.6. Many pilots felt that they could not have found the target without it. One concern with the arrow was that seeing head-on or tail-on aspect was difficult. Perhaps an underscore or overscore to differentiate the two would help. One pilot commented that it needed to be triple the presented size. A size increase may also help the tail and head aspect problem.

The missile icons were generally favored

with an overall score of 7.5. Some would have liked them as part of a de-clutter mode. One pilot commented that they took up too much display room for what they were offering, and another confused the outboard missiles with the target once. Every other comment was very positive.

The target aspect arc did not offer any information that was not already available to the pilot from the visible sight picture of the target. Therefore, this display's overall ranking was fairly low. It was also deemed to be too small and subtle to be of any use in the maneuvering portion of the engagement. Perhaps at long ranges in a multi-bogey scenario, that display would have more utility.

This test showed that the standard HUD weapon symbology may be inadequate for even experienced fighter pilots to maximize their weapon employment. A two-dimensional variation of the HMD weapon concept could be employed in a standard HUD. One of the most important elements of this design is that the pilot can readily see all weapon envelopes regardless of which is selected. That allows the pilot to plan ahead and be ready for that fleeting shot opportunity.

Subjective evaluation from this and other testing indicates that the three-dimensional target locator arrow is one of the best designs conceived under this project, but requires a raster graphics display medium. Some minor redesign or additional logic may be required in a multi-target environment to determine how one or more arrows would be presented.

Every pilot commented on a need for interactive control of the display. Most mentioned the use of hands on throttle and

stick (HOTAS), but a voice-activated method may work as well or better. That is, displays could be toggled on and off by name: for example, **Umbrella**, **Missiles**, and **Heading**. Due to the differences of opinions of the display concepts, allowing the pilot to customize their own display suites from a standard library may be an option worth exploring.

The range-lines display may be usable in other areas unrelated to air combat. For example, in a collision situation, the colliding aircraft, ship, car, etc. is on a constant bearing at decreasing range. This means that the object stays at one place in your field of view and just keeps getting bigger until it is finally perceived. That is, the most dangerous situation occurs when there is the least amount of object movement. With the range line display the greatest amount of movement occurs in this type of collision situation. This display could be used to get the pilot's attention, and with training the collision avoidance maneuver may be more obvious to the operator.

## **8.0 Future Directions**

This study has indicated that there is room for improvement over conventional HUD design. The NASA Langley HMD display suite has the potential to improve a pilot's situation awareness and ability to make timely decisions in the air combat environment. However, flight-worthy hardware will need to be light and unobtrusive before universal pilot acceptance is gained. The ideal hardware would preferably shine the display concepts in thin air or transmit them directly to the retina. A production HMD would have to complement and work seamlessly with other displays and aircraft systems to be truly effective. A combination of HOTAS and

voice commands would probably be the best pilot interface. With comparatively low cost software modifications and proper training, it may be possible to enhance the lethality of the average fighter pilot.

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13. ABSTRACT (Maximum 200 words)  A piloted simulation study was conducted in a dome simulator to evaluate several Helmet Mounted Display (HMD) formats developed as part of the NASA High Alpha Technology Program (HATP). The display formats conveyed energy management, spatial orientation and weapons management information. The HMD format was compared to a generic Heads Up Display (HUD) typical of current operational fighter aircraft. Pilots were tasked to spend as much time in a weapon solution as possible, to have the correct weapon selected for the envelope they were in, and to avoid the adversary's weapon envelope as much as possible. Several different displays were tested individually and simultaneously to see how separate display concepts coexisted. Objective results showed that the ability for the pilot to select the correct weapon for the envelope he was in increased by 50% in a moderate workload condition and 90% in a high workload condition with the HMD format. In the post-test comments pilots generally favored the helmet display formats over the HUD formats with a few instances where pilots preferred a simple numeric readout of the parameter. Short term exposure effects of the HMD on visual acuity were also measured and showed no adverse results.				
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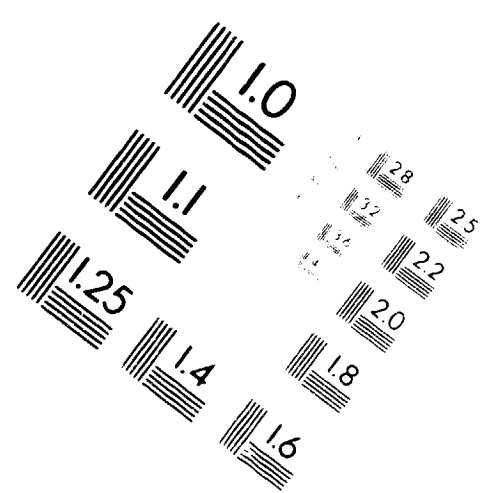
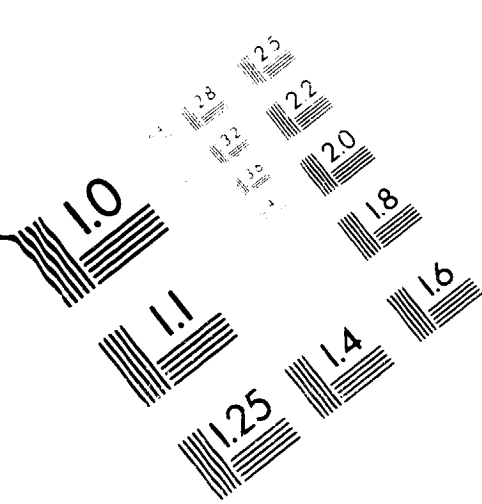


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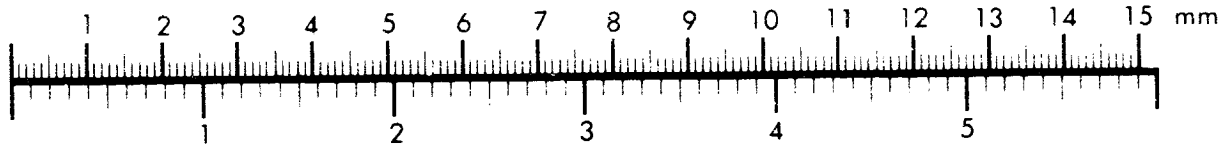
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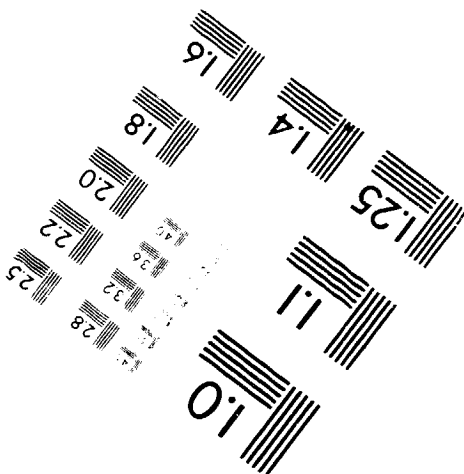
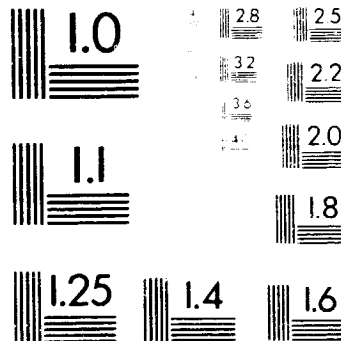
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